ORIGINAL ARTICLE

Eur. J. Anat. 21 (3): 225-233 (2017)

Evaluation of osteologic parameters of jugular foramen and its significance with respect to expanded endoscopic endonasal approach

Arpita Mahajan[1], Ranjana Verma[1], Shalini Kumar[1], Raj D. Mehra[1]

[1]Hamdard Institute of Medical Sciences and Research, Jamia Hamdard, New Delhi, India

SUMMARY

The jugular foramen (JF) is a large irregular hiatus, lies at the posterior end of the petro-occipital suture, posterior to the opening of carotid canal (CC) and it transmits major neurovascular structures. Tumors are the most common pathology involving structures present in JF. In the current scenario, lesions of structures present in JF progressing towards midline are suitably removed by expanded endoscopic endonasal approach (EEEA). In lieu of EEEA, we studied new parameters in relation to JF. The study was done on 50 human dry skulls with the help of sliding Vernier caliper and statistical analysis was done using SPSS software. Morphological study on the presence of dome, septa and relation of CC to JF was done. Morphometric parameters of JF and its distance from vomer, medial pterygoid plate (MPP), lateral pterygoid plate (LPP) and CC were studied. We also determined the distance from lateral and medial end of CC to the midsagittal plane (MSP). The dome of the jugular fossa (JFo) was seen in 42% skulls, each bilaterally and unilaterally. Complete and incomplete septa in JF were seen in 4% & 16% bilaterally and 8% & 18% unilaterally respectively. In the majority of the skulls, position of CC was anterior to JF and anteromedial was the next common position seen. Length & width of JF, depth of JFo, distance of JF from vomer, MPP, LPP & CC and the distance of CC to the MSP were more on the right side. This study may help neurosurgeons & ENT surgeons while approaching lesions around JF by EEEA.

Key words: Jugular foramen – Expanded endoscopic endonasal approach – Vomer – Medial pterygoid plate – Lateral pterygoid plate – Carotid canal – Midsagittal plane

INTRODUCTION

The jugular foramen (JF) is a large irregular hiatus that lies at the posterior end of the petro-occipital suture between the jugular process of the occipital bone and the jugular fossa (JFo) of the petrous part of the temporal bone. Exocranial opening of JF has alembic shape opening internally into the posterior cranial fossa and also leading to the JFo. The highest part of JFo is called dome, which lodges the superior bulb of the internal jugular vein (IJV) (Jovanovic et al., 2014). The exocranial opening of JF is directed anterolaterally and separated anteriorly from the inferior opening of the carotid canal (CC) by a crest, related laterally to the styloid process and medially to the hypoglossal canal (Pereira et al., 2010). A number of important structures pass through different parts of this foramen: inferior petrosal sinus (IPS) anteriorly, glossopharyngeal, vagus and accessory cranial nerves in the middle and IJV posteriorly (Standring, 2008).

Tumors are the most common pathology involving the structures present in JF. They include glo-

Corresponding author: Arpita Mahajan. Department of Anatomy, Hamdard Institute of Medical Sciences and Research, Jamia Hamdard, Hamdard Nagar, New Delhi, 110062 Delhi, India. Phone: +91-9958376111.

E-mail: arpitamahajan27@gmail.com

Submitted: 7 February, 2017. *Accepted:* 28 April, 2017.

mus jugular tumors (commonly from adventitia of jugular bulb), schwannomas of the lower cranial nerves, meningiomas, chordomas, chondrosarcomas, and metastatic tumors. Tumors of the JF may be confined to it or may extend into the nasopharynx through the eustachian tube and in the middle cranial fossa through the tegmen tympani or CC (Griessenauer et al., 2016). As the area of the JF is compact and compartmentalized, these tumors could be the reason for compression of neurovascular structures present there, especially the last four cranial nerves, causing varied symptoms, grouped as jugular foramen syndrome or Vernet's Syndrome (Sethi et al., 2011).

The pattern of invasion and destruction of the surrounding structures by the individual tumor directs the selection of the surgical approach to JF. The open surgical procedures include anterolateral (Postauricular transtemporal, Preauricular subtemporal and Infratemporal) and posterolateral (Retrosigmoid & Far lateral) approaches (Griessenauer et al., 2016), but lesions that are closer to the midline (clivus) are difficult to approach by this route. The alternative for these lesions is expanded endoscopic endonasal approach (EEEA), which has a potential to provide direct route into such lesions from medial to lateral direction, causing minimal manipulation of adjacent neurovascular structures (Kassam et al., 2005). During EEEA, the internal carotid artery (ICA) is used as important landmark as JF containing IJV is lateral to it and some cranial nerves (IX, X and XI) lie between them. This relationship is important for lateral positioning of the endoscope and dissecting instruments in lieu of protecting these structures in the path of approach (Prevedello et al., 2008). Also an anatomical understanding of the relationship of the carotid canal (which encases only a segment of the ICA) is of immense importance for the surgeon. Special care and a strong anatomical knowledge are needed to prevent complications such as ICA laceration, thrombosis and subsequent emboli (Alonso et al., 2016).

The review of literature revealed studies done all over the world on the morphology and morphometric measurements of JF (Sturrock, 1988; Hatiboglu et al., 1992; Pereira et al., 2010; Sharma et al., 2011; Vijisha et al., 2013; Gupta et al., 2014; Das et al., 2016) but there is scanty research on parameters of JF pertaining to EEEA (Ishwarkumar et al., 2015). Nowadays EEEA is a better option for lesions of JF progressing towards midline and needs more attention towards new morphometric parameters of JF in relation to vomer, medial pterygoid plate (MPP), lateral pterygoid plate (LPP), CC and distance of CC from midsagittal plane (MSP). Therefore, the primary aim of this study was to determine the abovementioned parameters in relation to JF in addition to the morphological features and morphometric measurements of JF.

MATERIALS AND METHODS

The study was carried out on 50 human dry skulls (100 JF) of unknown sex and age of north Indian origin procured from Department of Anatomy HIMSR and MAMC, New Delhi. Skulls were all recent belonging to the latter half of twentieth century with good condition, i.e,. intact JF, pterygoid plates, vomer and CC were selected for study. The following morphologic features were observed:

Presence or absence of dome of JFo

Complete and incomplete septation of JF

Position of the CC in relation to the JF (position of CC was considered with respect to a parasagit-

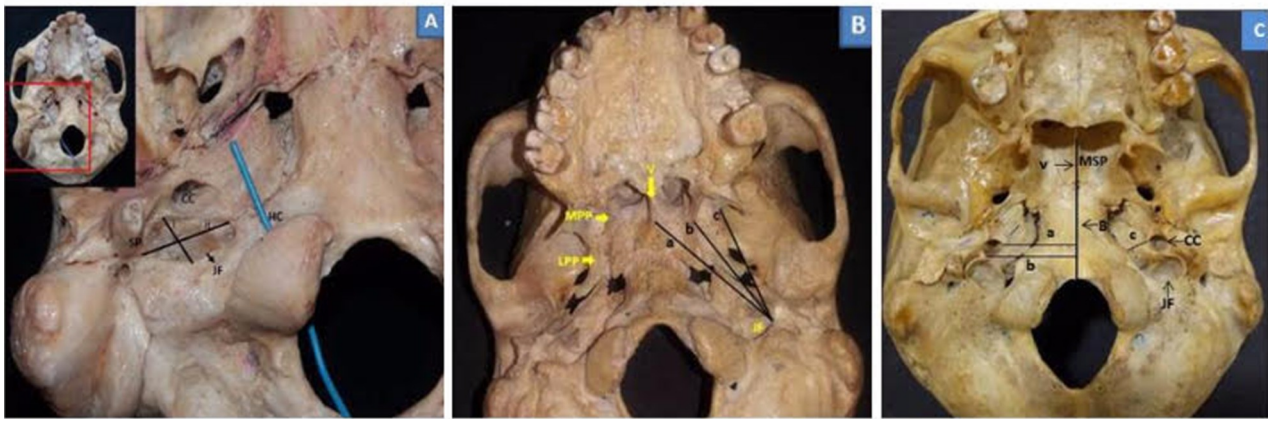

Fig 1. Methods to measure morphometric parameters of JF and its relation to important bony landmarks. **A:** Inset is showing the complete skull and the area studied has been marked in red box. Jugular foramen (JF) is seen from exocranial side and its relationship to carotid canal (CC), styloid process (SP) and hypoglossal canal (HC, blue probe inserted in the canal). Line segment (i) indicate maximum width of JF and line segment (ii) is maximum length along the long axis of the JF. **B:** (a)- distance of posterior end of JF from vomer, (b)- distance of posterior end of JF from MPP and (c)- distance of posterior end of JF from LPP. **C:** (a)- distance of medial end of CC from MSP, (b)- distance of lateral end of CC from MSP and (c)- closest distance between JF and CC. Vomer (V), Medial pterygoid plate (MPP), Lateral pterygoid plate (LPP), Basion (B), Mid-sagittal plane (MSP).

tal line passing through mid-point of JF)

The morphometric measurements were taken from the exocranial aspect of the skulls using Vernier caliper with accuracy of 0.01 mm by two different observers, and the average of the two observations was considered to reduce the error rate. The length and width of JF were calculated along the long axis and perpendicular to it respectively, due to the irregularity of the foramen and its oblique orientation (Fig. 1A). The distance of JF from different bony landmarks was measured from the posterior end of its long axis (Fig. 1B). The midsagittal plane (MSP) was marked as a line extending from schendylesis between two alae of vomer and sphenoidal rostrum to the basion (Fig. 1C). The following parameters were noted:

Exocranial length of JF
Exocranial width of JF
Depth of dome of JFo if dome is present
Distance of posterior end of long axis of JF from vomer
Distance of posterior end of long axis of JF from MPP
Distance of posterior end of long axis of JF from LPP
Closest distance between JF and CC
Distance of medial end of CC to MSP
Distance of lateral end of CC to MSP

The statistical analysis was done by SPSS software package. Descriptive statistics like range, mean and standard deviation were evaluated for all the parameters collected. For all analyses p value of <0.05 was considered to be statistically significant and < 0.01 as highly significant.

RESULTS

Morphologic features (Table 1)

Dome of JFo was present bilaterally in 42% skulls and unilaterally in 42% (right side 28% and left side 14%). It was absent in 16% skulls bilaterally (Fig. 2).

Septation in JF: Complete septation in JF was seen in 4% skulls bilaterally and 8% unilaterally while incomplete septation was noted in 16% skulls bilaterally and 18% unilaterally. In some cases, both complete and incomplete septum in JF was observed in the same skull. In one skull on the right side, we observed two complete septa in JF dividing it into three compartments. In another skull, in addition to bilateral complete septa in JF there was also a separate opening for IPS on both sides (Fig. 3).

Relationship of CC to JF: CC was anterior to JF in 24%, anteromedial in 16% and anterolateral in 12% skulls bilaterally. In 48% of skulls the position

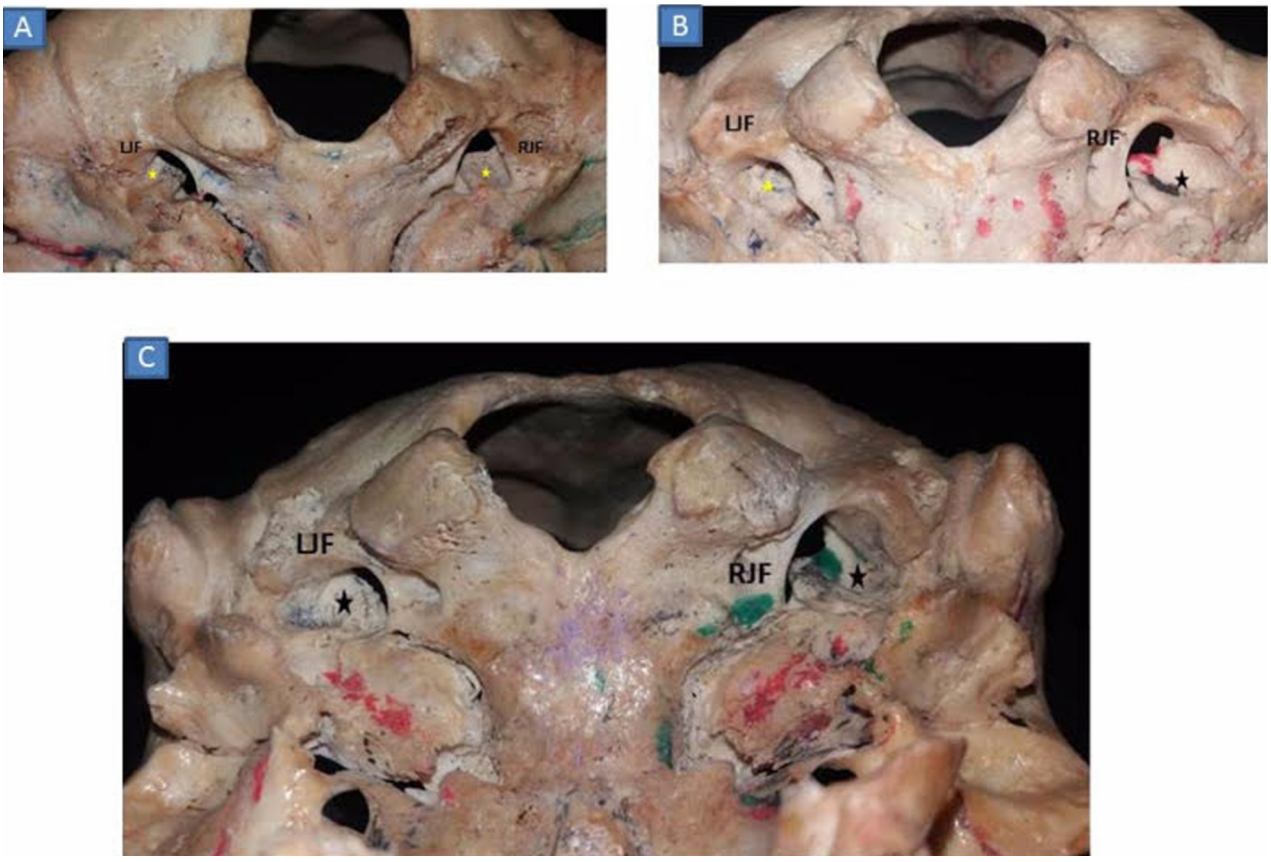

Fig 2. Showing dome of jugular fossa (JFo). **A:** Bilateral absence of dome, **B:** Unilateral presence of dome in the RJF, **C:** bilateral presence of dome. Yellow star- absence of dome and black star- presence of dome, Right jugular foramen (RJF), and Left jugular foramen (LJF).

of CC in relation to JF was different on the right and the left side. CC was anterior in 44% (right-30%, left-14%), anteromedial in 40% (right-10%, left-30%) and anterolateral in 12% (right-8%, left-4%) skulls (Fig. 4).

Morphometric parameters (Tables 2 &3)

Dimensions of JF & JFo: The length of JF was almost the same on both sides (right side 17.94±3.26 mm and left side 17.90±3.29 mm). The width of JF was greater on the right side (10.59±2.39 mm) as compared to the left (8.41±1.74 mm), and the difference was statistically highly significant. The depth of dome of JFo when present showed a value of 9.55±6.6mm on the right side and 7.3±7 mm on the left side (Table 2).

Distance between different bony landmarks: The mean distance between JF & vomer on the the right side was 49.43±3.23 mm and on the left was 48.94±3.16 mm. The mean distance from JF to MPP and LPP on the right side was 40.04±3.30 mm & 35.43±4.21 mm and on the left side 39.27±3.19 mm & 34.37±3.94 mm respectively, these differences were statistically significant. The closest distance from JF to CC was 7.86±1.34 mm

Table 1. Morphological features of Jugular foramen (JF) and Jugular fossa (JFo).

Sl. no	Morphological features		Bilateral		Unilateral					
					Total		Right		Left	
			N	%	N	%	N	%	N	%
1.	**Dome in JFo**		21	**42**	21	**42**	14	28	7	14
2.	**Septation***	Complete	2	**4**	4	**8**	1	2	3	6
		Incomplete	8	**16**	9	**18**	5	10	4	8
3.	**Position of the CC in relation to the JF**	Anterior	12	**24**	22	**44**	15	30	7	14
		Anteromedial	8	**16**	20	**40**	5	10	15	30
		Anterolateral	6	**12**	6	**12**	4	8	2	4

N= total number of skulls
* In some cases, incomplete and complete septa was seen in same skull.

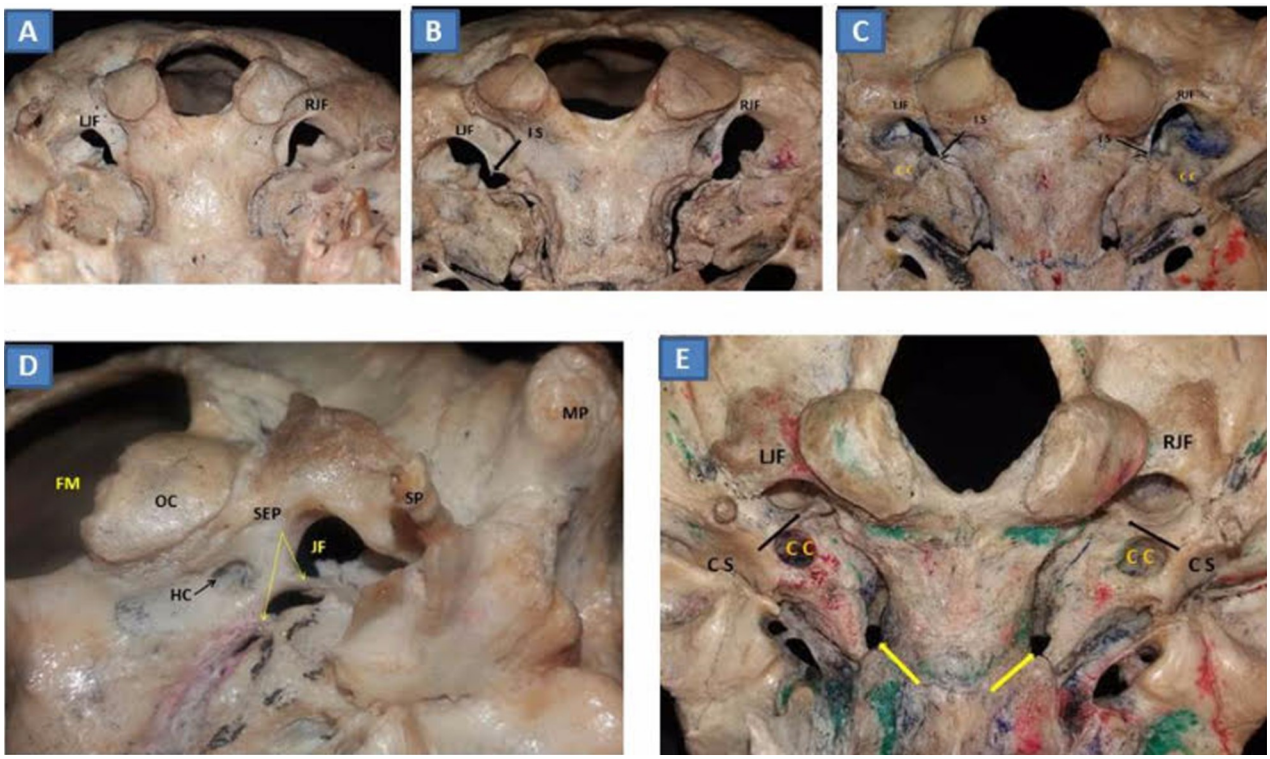

Fig 3. Septation in JF. **A:** Normal JF without any septa, **B:** Unilateral incomplete septa (IS) on left side, **C:** Bilateral incomplete septa, **D:** Unilateral two complete septa (SEP) on right side dividing JF into three compartments, **E:** Bilateral complete septa (CS) & separate opening of inferior petrosal sinus (marked with yellow arrows). Right jugular foramen (RJF), Left jugular foramen (LJF), Carotid canal (CC), Styloid process (SP), Hypoglossal canal (HC), Mastoid process (MP), occipital condyle (OC), Foramen magnum (FM).

on the right side and 7.6±1.55 mm on the left side. The distance of the lateral and medial end of CC from MSP was 33.48±2.05 mm & 26.9±1.67 mm on the right side and 32.60±2.03 mm & 26.36±1.89 mm on the left side respectively, these differences were also statistically significant (Table 3).

DISCUSSION

The JF is an anatomically complex region of the cranial base and tumors around it like glomus jugulare may compress structures traversing the foramen. Tumors, especially those with caudal and medial extensions, can be suitably approached by EEEA (Kassam et al., 2005). It provides direct access, better illumination and visualization of the tumor in deeper seated areas with minimal postoperative complications as compared to open skull base surgeries (Verillaud et al., 2012). EEEA needs attention regarding some new morphometric parameters like distance of JF from vomer, pterygoid plates, CC and distance of CC from MSP. In the present study, a sincere effort has been made to study the complex anatomy of JF and its relation to different bony landmarks.

In the present study, **dome of JFo** was seen both bilaterally and unilaterally in 42% of skulls each, which was closer to findings of some authors ranging between 49-58% bilaterally and 36-41.2% unilaterally (Sturrock, 1988; Hatiboglu et al., 1992, Sharma et al., 2011) while it also showed variability with findings of some other authors (Patel et al., 2007; Pereira et al., 2010; Vlajkovic et al., 2010; Singla et al., 2012; Vijisha et al., 2013). The dome of JFo was absent bilaterally in 16% skulls in our study, while Sturrock (1988) and Hatiboglu et al. (1992) reported it in 9.6% and 10.3% respectively. The JFo along with the superior bulb of IJV forms the floor of the middle ear cavity (Standring S, 2008). Many cases of glomus jugulare tumours erode this floor and penetrate into the middle ear cavity (Wyscoki et al., 1999). The absence of dome may decrease the chances of penetration of tumors into middle ear cavity. **Complete septation** of JF was observed in 4% skulls on both sides in the present study and it ranged between 0.9%-

Table 2. Morphometric parameters of Jugular foramen (JF) and Jugular fossa (JFo).

Morphometric measurements of JF	Right (mm)		Left (mm)		P-value
	Range	Mean±SD	Range	Mean±SD	
Length of JF	11-23	17.94±3.26	12-23	17.90±3.29	0.918
Width of JF	6-15	10.59±2.39	5-11	8.41±1.74	**0.000****
Depth of JFo	8-19	9.55±6.6	10-20	7.3±7	0.075

** statistically highly significant.

Table 3. Distance of Jugular foramen (JF) from different bony landmarks and distance of CC from MSP.

Distances b/w different bony landmarks	Right(mm)		Left(mm)		P-Value
	Range	Mean±SD	Range	Mean±SD	
Distance between JF & Vomer	40-56	49.43±3.23	42-55	48.94±3.16	0.196
Distance between JF & MPP	31-45	40.04±3.30	33-45	39.27±3.19	**0.045***
Distance between JF & LPP	21-41	35.43±4.21	25-41	34.37±3.94	**0.021***
Closest distance b/w CC and JF	5-10	7.86±1.34	4-11	7.6±1.55	0.124
Lateral end of CC from MSP	30-37	33.48±2.05	28-36	32.60±2.03	**0.000****
Medial end of CC from MSP	24-30	26.9±1.67	22-30	26.36±1.89	**0.039***

* statistically significant, ** statistically highly significant

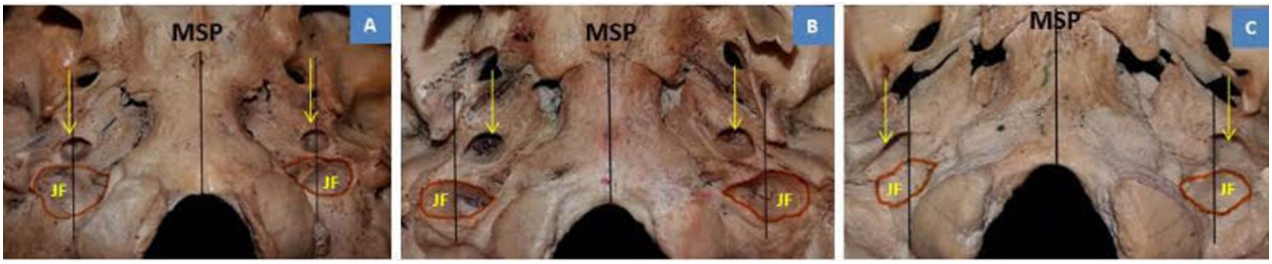

Fig 4. Showing position of CC in relation to JF. A: CC anterior to JF, B: CC anteromedial to JF, C: CC anterolateral to JF. Midsagittal plane (MSP), Jugular foramen (JF), Yellow arrow-carotid canal.

10.6% in other studies (Pereira et al., 2010; Sharma et al., 2011; Sethi et al., 2011 and Singla et al., 2012;) Unilateral complete septation was 8% in our study which falls in the range (4% - 40.6%) reported by other authors (Sturrock, 1988; Hatiboglu et al., 1992; Patel et al., 2007; Sharma et al., 2011; Singla et al., 2012, Vijisha et al., 2013). **Incomplete septation** of JF was seen bilaterally in 16% and unilaterally in 18% in the present study, which was closer to the findings of some other authors (Sturrock, 1988; Hatiboglu et al., 1992; Sethi et al., 2011; Sharma et al., 2011). The value reported by some Indian researchers was higher compared to the current study (Patel et al., 2007; Vijisha et al., 2013; Gupta et al. 2014) (Table 4). **Separate foramen for IPS** was seen in 2% skulls bilaterally in the present study, while Hatiboglu et al. (1992) reported in 5.6% (right) & 4.6% (left), Rhonton et al. (2000) observed in 6% skulls and Khanday et al. (2013) in 8.6% (right) & 9.8% (left) skulls. These septations can compress the structures passing through JF, thereby simulating the clinical presentation of glomus jugulare tumour.

Moore et al. (2010) found the external opening of the CC was anterior to that of the JF while Somesh et al. (2014) reported it anterolateral. According to Naidoo et al. (2016), CC was anterior to JF in 75.9%, anteromedial in 12.3% and anterolateral in

Table 4. Comparison of morphological features of Jugular fossa (JFo) and Jugular foramen (JF) in present study with different populations in the world (B/L- bilateral, U/L-unilateral, R-right & L-left, Popn-Population, A- Absent).

Author & Year	Popn	Dome			Septa					
					Complete			Incomplete		
		B/L	U/L		B/L	U/L		B/L	U/L	
			R	L		R	L		R	L
Sturrock (1988)	Romano - British	53.9%	30.1%	6.4%	-	3.2%	3.2%	-	1.3%	10.9%
Hatiboglu et al. (1992)	Anatolian	49%	36.6%	4.6%	-	5.6%	4.3%	-	2.6%	19.6%
Patel et al. (2007)	Indian	21%	38.5%	14.3%	-	23%	17.6%	-	49.5%	59.3%
Pereira et al. (2010)	Brazil	68.5%	-	-	0.9%	-	-	0.9%	-	-
Vlajkovic et al. (2010)	Serbian		68%			24%			-	
Sethi et al. (2011)	Indian	-	-	-	10.6%	A	A	A	7.1%	4.3%
Sharma et al. (2011)	Indian	58%	28%	8%	6%	2%	2%	18%	4%	14%
Singla et al. (2012)	Indian	66%	6%	16%	10%	4%	-	-	-	-
Vijisha et al. (2013)	Indian	70%	26.6%	3.3%	-	10%	6.6%	-	73.3%	80%
Gupta et al. (2014)	Indian	-	74%	58%	-	-	-	-	56%	58%
Present study	Indian	42%	28%	14%	4%	2%	6%	16%	10%	8%

Table 5. Comparison of morphometric parameters of Jugular foramen (JF) in present study with different populations in the world

Author & Year	Population	Exocranial length		Exocranial width		Depth of dome of JFo	
		Right	Left	Right	Left	Right	Left
Ekinci et al. (1997)	Turkish	16	15.5	8.4	7.6	-	-
Aydinlioglu et al. (2001)	Turkish	13.7	12.3	12.2	10.9	-	-
Idowu et al. (2004)	Nigerian	13.9	14.11	10.22	9.57	-	-
Pereira et al. (2010)	Brazilian	15.82	15.86	9.21	8.65	-	-
Sharma et al. (2011)	Indian	15.59	13.83	9.02	7.73	-	-
Singla et al. (2012)	Indian	15.67	14.85	9.32	7.34	11.1	11.04
Kotgirwar et al.(2013)	Indian	-	-	-	-	11.78	9.84
Vijisha et al. (2013)	Indian	17.33	15.3	12.13	9.27	-	-
Gupta et al. (2014)	Indian	16.52	16.02	11.22	9.52	11.75	11.13
Ishwarkumar et al. (2015)	South African	12.89	12.12	6.43	5.39	-	-
Das et al. (2016)	Indian	13.72	13.07	9.37	6.88	12.54	8.72
Jasuja et al. (2016)	Indian	17.28	16.7	11.80	10.04	-	-
Present study	Indian	17.94	17.90	10.59	8.41	9.55	7.3

11.7%. In the present study CC was anterior, anteromedial and anterolateral to JF in 24%, 16% and 12% skulls bilaterally and 44%, 40%, and 12% skulls unilaterally respectively. More common anteromedial location of CC as seen in the present study indicates that neurosurgeons should be aware of this relationship to save ICA while using EEEA.

The maximum length of JF on the right and left side in the present study was 17.94 mm and 17.9 mm which was closer to findings of Indian studies (Singla et al., 2012; Vijisha et al., 2013; Gupta et al., 2014; Jasuja et al., 2016) while it is lower in most studies done outside India (Aydinlioglu et al., 2001; Idowu, 2004; Ishwarkumar et al., 2015). The maximum width of JF on the right and left side was 10.59 mm and 8.41 mm and the difference was statistically highly significant. These values were closer to other Indian studies (Vijisha et al., 2013; Gupta et al., 2014; Jasuja et al., 2016) and non-Indian studies (Aydinlioglu et al., 2001; Idowu, 2004). The depth of jugular fossa observed in our study was lower in comparison to other studies (Singla et al., 2012; Kotgirwar et al., 2013; Gupta et al., 2014; Das et al., 2016) (Table 5). All the dimensions of JF in our study were higher on the right side as compared to the left side. The shape and size of the JF is related to the size of the IJV and the presence or absence of a prominent superior bulb. It might be expected that the right foramen would usually be larger than the left, since the textbooks classically describe the superior sagittal sinus as draining into the right transverse sinus. There is a wide variation in the anatomy of the intracranial venous sinuses, which accounts for variation in size and shape of JF (Sturrock, 1988). A higher JFo may cause conductive hearing loss because of its contact with the tympanic membrane, thus affecting ossicular chain integrity. It may also cause complications during cochlear implantation (Weiss et al., 1997). Higher JFo is a risk factor during surgery for vestibular schwannomas, as it lies very close to the internal acoustic meatus (Gupta et al., 2009).

Distance of JF from vomer, MPP and LPP was 49.43 mm, 40.04 mm & 35.43 mm on the right side and 48.94 mm, 39.27 mm and 34.37 mm on the left side respectively in the present study which was higher as compared to the study done by Ishwarkumar et al. (2015). The reason for the different observations could be attributed to the reference point (anterior end of JF by Ishwarkumar et al. whereas we took the posterior end of JF). The closest distance of CC from JF was 7.86 mm on the right side and 7.7 mm on the left side in the present study and to our knowledge this is the first report of this value (Table 6). The distance of medial end of CC from MSP was 26.9 mm on right side and 26.36 mm on the left side which was similar to other studies (Calguner et al., 1997; Sharma et al., 2011; Ahmed et al., 2015; Somesh et al., 2016). The distance of lateral end of CC from MSP was 33.48 mm on the right side and 32.6 mm on the left side which was similar to findings of Somesh et al. (2016).

Conclusion

The present study investigated a number of unique morphological and morphometric parameters of JF. The dome of JFo was seen in the majority of the skulls and incomplete septum of JF was seen more frequently as compared to complete septum. The presence of septa dividing JF into compartments can cause compression of the neurovascular structures passing through this foramen. Moreover the position of CC was anterior to JF in maximum skulls but anteromedial location was also seen frequently. The mean size of the JF, depth of dome of JFo and distance of JF from different bony landmarks were greater on the right side. The relation of CC to JF and morphometric data observed in the present study are of enormous value to neurosurgeons and ENT surgeons while performing surgeries by EEEA for tumours around JF with medial extension.

ACKNOWLEDGEMENTS

The authors are extremely thankful to Dr. Neelam Vasudeva, Head, Department of Anatomy, MAMC, New Delhi for permitting us to do a study on skulls available in the department, and to the institutions responsible for research support and/or financial support (Hamdard Institute of Medical Sciences and Research, Jamia Hamdard, New Delhi, and Maulana Azad Medical College, New Delhi).

REFERENCES

AHMED MM, JEELANI M, TARNUM A (2015) Anthropometry: A comparative study of right and left sided foramen ovale, jugular foramen and carotid canal. *Int J Sci Study,* 3(5): 88-94.

ALONSO F, BERNARD S, IRWIN PA, R. TUBBS

Table 6. Comparison of distance of Jugular foramen (JF) from different bony landmarks

Author & Year	JF from vomer (mm)		JF from MPP (mm)		JF from LPP (mm)		cc from JF (mm)	
	Right	Left	Right	Left	Right	Left	Right	Left
Ishwarkumar et al. (2015)	34.21	33.68	25.86	24.32	23.97	22.89	-	-
Present study	49.43	48.94	40.04	39.27	35.43	34.37	7.86	7.7

I, IWANAGA J, LOUKAS M, OSKOUIAN RJ, TUBBS RS (2016) The relationship between the carotid canal and mandibular condyle: an anatomical study with application to surgical approaches to the skull base via the infratemporal fossa. *Anatomy*, 10(3):193-199.

AYDINLIOGLU A,YESILYURT H, DIYARBAKIRLI S, ERDEM S, DASTAN A (2001) Foramen Jugulare: A local investigation and a review of the literature. *Kaibogaku Zasshi*, Journal of Anatomy 76(6): 541-545.

CALGUNER E, TURGUT HB, GOZIL R, TUNC E, SEVIM A, KESKIL S (1997) Measurements of the carotid canal in skulls from Anatolia. *Acta Anat*, 158: 130-132.

DAS SS, SALUJA S, VASUDEVA N (2016) Complete morphometric analysis of jugular foramen and its clinical implications. *J Craniovert Jun Spine*, 7: 257-264.

EKINCI N, UNUR E (1997) Macroscopic and morphometric investigation of the jugular foramen of the human skull. *Kaibogaku Zasshi*, Journal of Anatomy , 72(6): 525-529.

GRIESSENAUER CJ, MCGREW B, MATUSZ P, De CARO R, LOUKAS M, TUBBS RS (2016) Surgical approaches to the jugular foramen: A comprehensive review. *J Neurol SURG,* 77(3): 260-264.

GUPTA C, KURIAN P, SEVA KN, KALTHUR SG, D'SOUZA AS (2014) A morphological and morphometric study of jugular foramen in dry skulls with its clinical implications. *J Craniovertebr Junction Spine,* 5(3): 118-121.

GUPTA T, GUPTA SK (2009) Anatomical delineation of a safety zone for drilling the internal acoustic meatus during surgery for vestibular schwanomma by retrosigmoid suboccipital approach. *Clin Anat*, 22(7): 794-799.

HATIBOGLU MT, ANIL A (1992) Structural variations in the jugular foramen of the human skull. *J Anat*, 180: 191-196.

IDOWU OE (2004) The jugular foramen - a morphometric study. *Folia Morphol (Warsz)*, 63(4): 419-422.

ISHWARKUMAR S, NAIDOO N, LAZARUS L, PILLAY P, SATYAPAL KS (2015) An osteometric evaluation of the jugular foramen. *Int J Morphol,* 33(1): 251-254.

JASUJA VR, KULKARNI PG, BORATE SM, WADEKAR PR, PUNYANI SR (2016) Morphometric and morphologic study of jugular foramen in Western Maharashtra region of India. *Int J Anat Res*, 4(1): 2085-2089.

JOVANOVIC I, UGRENOVIC S, STOJANOVIC V, KRSTIC M, TRANDAFILOVIC M, CUKURANOVIC J (2014) Morphometric characteristics of jugular foramen and sigmoid sinus groove: their possible connections with high jugular bulb presence. *FU Med Biol,* 16(1): 12-17.

KASSAM A, GARDNER P, SNYDERMAN C, CARRAU R, ZIMMER L, HIRSCH B, MINTZ A (2005) Endoscopic, expanded endonasal approach to the jugular foramen. *Oper Tech Neurosurg*, 8: 35-41.

KHANDAY S, SUBRAMANIAN RK, RAJENDRAN M, HASSAN AU, KHAN SH (2013) Morphological and morphometric study of jugular foramen in South Indian population. *Int J Anat Res,* 1(3): 122-127.

KOTGIRWAR S, ATHAVALE S (2013) Morphometric study of jugular foramen in adult South Indian skulls. *J Anat Soc India*, 62: 166-169.

MOORE KL, DALLEY AF, AGUR AMR (2014) *Clinically oriented Anatomy*. 7th Ed. Lippincott Williams & Wilkins, USA, pp 830-831.

NAIDOO N, LAZARUS L, AJAYI NO, SATYAPAL KS (2016) An anatomical investigation of the carotid canal. *Folia Morphol (Warsz)*, doi: 10.5603/FM.a2016.0060.

PATEL MM, SINGEL TC (2007) Variations in the structure of the jugular foramen of the human skull in Saurashtra region. *J Anat Soc India*, 56(2): 34-37.

PEREIRA GA, LOPES PT, SANTOS AM, KREBS WD (2010) Morphometric aspects of the jugular foramen in dry skulls of adult individuals in Southern Brazil. *J Morphol Sci*, 27(1): 3-5.

PREVEDELLO DM, KASSAM AB, CARRAU R, GARDNER P, ZANATION A, MINTZ A, SNYDERMAN C (2008) The expanded endoscopic endonasal approaches for the skull base. *J Bras Neurocirurg,* 19(2): 18-29.

RHOTON AL (2000) Jugular foramen. *Neurosurg*, 47: 267-285.

SETHI R, SINGH V, KAUL NV (2011). Morphological variations of a jugular foramen in North Indian human adult skulls. *Indian J Otol*, 17(1): 14-16.

SHARMA NA, GARUD RS (2011) Foramina of the posterior cranial base: A study of adult Indian skulls. *Rev Arg Anat Clin,* 3(2): 89-98.

SINGLA A, SAHNI D, AGGARWAL A, GUPTA T, KAUR H (2012) Morphometric study of the jugular foramen in Northwest Indian population. *J Postgrad Med Educ Res*, 46(4): 165-171.

SOMESH MS, SRIDEVI HB, MURLIMANJU BV, PAI SR (2014) Morphological and morphometric study of carotid canal in Indian population. *Int J Biomed Res*, 5(7): 455-460.

STANDRING S (2008) Gray's Anatomy: The Anatomical Basis of Clinical Practice, 40th Ed. Elsevier Churchill Livingstone, London, pp 415.

STURROCK RR (1988) Variations in the structure of the jugular foramen of the human skull. *J Anat,* 160: 227-230.

VERILLAUD B, BRESSON D, SAUVAGET E , MANDONNET E, GEORGES B, KANIA R, HERMAN P (2012) Endoscopic endonasal skull base surgery. *Eur Ann Otorhinolaryngol Head Neck Dis*, 129(4): 190-196.

VIJISHA P, BILODI AK, LOKESHMARA N (2013) Morphometric study of jugular foramen in Tamil

Nadu region. *Nat J Clin Anat*, 2(2): 71-74.

VLAJKOVIC S, VASOVIC L, BJELAKOVIC MD, STANKOVIC S, POPOVIC J, CUKURANOVIC R (2010) Human bony jugular foramen: Some additional morphological and morphometric features. *Med Sci Monit*, 16(5): 140-146.

WEISS RL, ZAHTZ G, GOLDOFSKY E, PARNES H, SHIKOWITZ MJ (1997) High jugular bulb and conductive hearing loss. *Laryngoscope*, 107(3): 321-327.

WYSOCKI J, CHMIELIK LP, GACEK W (1999) Variability of magnitude of the human jugular foramen in relation to conditions of the venous outflow after ligation of the internal jugular vein. *Otolaryngol Pol*, 53(2): 173-177.